How Radar Technology Changed the Course of the World after World War II - Science and Technology

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Abstract

After the independent invention of radar in the early 1930s, the development of radar went rapidly during World War II (1939-1945) when both Axis and Allied forces relied on the system to get an edge over the other. Ever since the war, radar technology has substantially increased in its innovation and capability throughout the years. This paperexamines the progress of radar technology following World War II (1939-1945) with an aim to provide a landscape of the prevalent radar system during the war which was mono-pulse tracking radar systems and moving-target indication (MTI) system. After a thorough background study of the past radar system, the paper highlights application of the newer developed Phased Array Radar System which was formulated out through the implementation of the improved capabilities of both prevalent systems.Moreover, the paper provides a brief overview of the modular system and formulates a time frame relating to the development of radar research. Thus, the paper, later on, foresees the prominent future where phased array systems could be expanded to civilian and non-civilian technological research by providing thorough research and comparative analysis. Phased array systems are found to a prominent possible cheaper alternative for the civilian and non-civilian system. It shows prominence to be an effective useful tool for radar systems.

Keywords: Radar technology, World War, Phased Array Radar Systems, Synthetic-Aperture Radar, Civilian applications

Introduction

Radar technology has modified the world both technological and through the non-civilian application. The modular technology is implemented in various non-civilian and civilian fields. The phased array radar system has a modular application even in today's world. The system transmits a radiation signal and also is cheap. It could be a cost-effective application in civilian as well as non-civilian fields.

Radar is a modular detecting system that utilizes radio waves to know the whereabouts of position, angle and velocity of an object. It is generally utilized to detect ships, missiles, aircraft as well as other objects. A radar system operates through the emission of electromagnetic energy. It then detects the echo that is returned by the reflecting object, i.e., warships and aircraft. Radar can track the angle of arrival, path trajectory as well as determine the future location of the warship. "Doppler effect helps to determine the movement of echo signal which is used to determine the variation of stationary objects, i.e., aircraft carriers from land and sea clutter"(Skolnik, 2019, p. 13). Doppler Effect could be used for detecting the location of a stationary aircraft structure based on data that is received through the clutter. The phenomenon is used for the development of Radar technology.

Radar was independently invented in the mid-1930s. The first proper description was stated by Young and Page in the Naval Research Laboratory at the end of 1934 where the narrow-band substance was found to create a stretching effect on the echo of an electromagnetic wave (Taveniku, 1997, p. 129). Radar was thought of as a digitization process to improve the air-defence system of countries. "Varying forms of Radar are common namely height-finding radar, gap-filler radars, and long-range radar. The return of the wave's intensity was measured with a variation of frequency. A bump in relative frequency was seen when a certain frequency was reached on the Doppler spectrum"(Clark, 2000, pp. 172–175). The presence of a bump allows the entire radar system to locate the distance of the object based on distance and intensity. The path travelled is measured to form a clear indication of the location of the object.

In general, radar used an amplifier, receiver and transmitter to send waves of signal through the mixture. The antenna was used as the standard receiver which received a tracking element with a pencil beam pattern as mentioned by Clark. A block diagram representing the passage of information is shown in Figure 1.

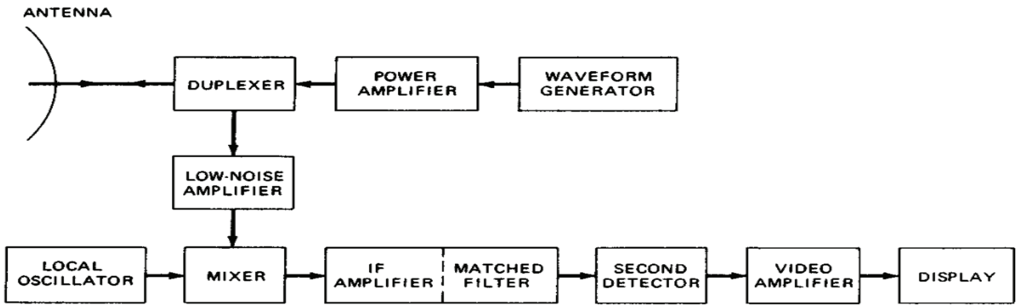

FIG. 1.1 Simple block diagram of a radar employing a power amplifier transmitter and a superheterodyne receiver.

Figure 1: A data transfer pattern in Radar (Taveniku, 1997, p. 130)

In recent terms, through the development of Radar, aircraft have been trying to avoid detection by trying to disrupt the electromagnetic signal sent by the Radar system. A common ploy is to disrupt the noise figure and the RF peak signal which in turn helps to fade out the cluster signal in the system (Owen et al., 2014, p. 550). To combat the ploy sent by various aircraft to avoid detection, surveillance radar networking system have moved to multi-phased array reorganization system. "The US airports and the National Center for Atmospheric Research (NCAR) use a multi-phased array for surveillance purposes"(Weber et al., 2007, p. 1746). The presence of a multi-phased array system has expanded from its early detection and surveillance use. It is crucial to grasp an understanding of the working principleof radar systems to expand the application of multi-phased array systems.

Working of Radar Technology

Radar technologies are used to detect attacking aeroplanes. The radar ranging and tracking system firstly detects the attacking aeroplane when it enters the neutral hemisphere. Alongside a tracker, an optical range finder and tracking telescope help in perceiving the attacking airplanes. The ranging and tracking system works by passingan electromagnetic wave through the system. The tracking system tracks signal based on magnetic permeability, conductivity, and permittivity. The wave works as a function defined in Equation 1(Aardal et al., 2013, p. 1145).

$E(x, t)= f\,[E_0 e^{-(\alpha+ik)\,x+\,i\,(\omega t)}]$	Equation 1

where α = attenuation constant and ω = angular velocity of the wave.

The data is then transmitted using a data transmission cable. The system works comprehensively to detect the attacking aeroplanes. It predicts the position of the aeroplane which is a function of the inclining angle, height and velocity of the aeroplane. Anti-aircraft guns articulate the position and then a shell is sent. A radar system also helps in creating a path for the shell which is sent out by the anti-aircraft gun. The modular working can be carefully understood from the demonstration in Figure 2.

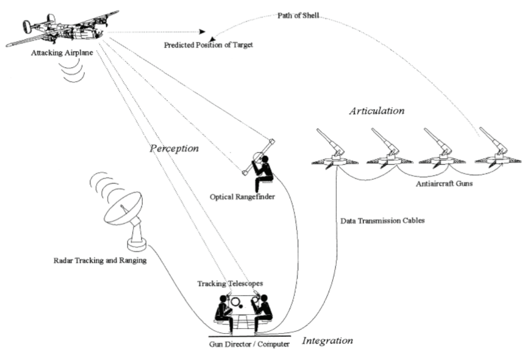

Figure 2: Working of a model radar system as per Mindell (Mindell, 2013, p. 40)

Methodology

The paper uses relevant articles, paper and conference proceeding to formulate a proper background for the project. The statement and concepts for the paper are brainstormed and varying concepts are screened. Mathematical as well as schematic interpretations are drawn and explained in the manuscript. Descriptive and quantitative variations are stated. The inner mechanisms and working are extrapolated to prepare a comparative study. A proper assessment is conducted for synthesizing the information into relevant portions.

A Dive into Radar History

Radar technology was a definite need during World War II (1939-1945). The axis and the allied parties tried to outmanoeuvre each other during the war. Both started to develop better effective and efficient Radar technology. Both sides looked towards Radar technology to give them the edge in navy and aerial combat. The first move was made bythe Japanese Army when a Tachi-6 air-warning radar transmitter was used as a camouflaged antenna to capture signals from allied troops near Noemfoor Island in New Guinea in 1940. Allies went through years and years of despair trying to build a better radar system than the axis. A breakthrough came in 1942 when Alan Turningdeveloped the channel. The detecting commerce radar detecting system identified the presence of warships (Pickering, 1995, p. 43; Wolters & Brown, 2002, p. 235). The detection of warships allows the allies forces to pick up the danger spots around the warships and avoid them. It provided the allies with a huge boost against the axis forces and eventually helped the allies power to win the war.

During the war, in 1945, Bell Labs (BTL) also was developing a predicting tracker and target recognizing position indicator for anti-aircraft guns. It used electromechanical servo computing driven systems with a feedback amplification system. It utilized built-in BTL input through optical telescopes. Mindell (2013, pp. 28-29) describes the prototype which was used at Pearl Harbor. The prototype included anXT-1 tracker and SCR-584 for proper detection of stationary objects. The radar technologies was a crucial point in helping the allies secure the war against the axis power.

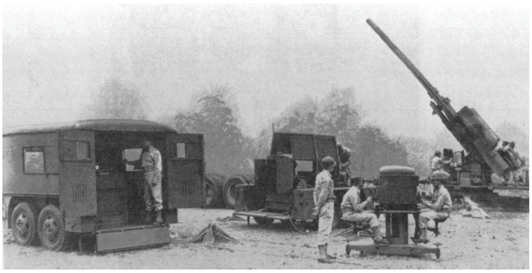

Figure 3: M-9 anti-aircraft detectors with an SCR-584 radar detector system (Mindell, 2013, p. 41)

Figure 3 displays an M-9 anti-aircraft detector system that operated through a radar detection platform also called radar trackers. The preliminarily used radar trackers were further modified to formulate mono-pulse and moving target indicator systems. The pre-developed system help creates future radar technologies including a phased-array system.The crucial historical development by Bell Labs helped to create the Radar system which we see in the 21st century.

Radar Systems

The radar system measures the method of arrival based on a narrow antenna beam. The existence of relative motion is calculated by the radar system. The target's relative velocity, angle of attack and frequency of the reflected wave is measured to determine the target velocity and distinguish it from other stationary objects (Skolnik, 2019, p. 15). The most prominent radar systems just after World War II were mono-pulse tracking radar and Moving-target indication systems.

Mono-Pulse Tracking Radar System

Mono-pulse tracking system tracks the overall coordinates and position of a target to realize the required target. In general,a mono-pulse tracking system used four antennas that track the respective angular position of each point of the object. Bhilegaonkar & Dhande (2013, p. 58) compared the phase angle, amplitude and amplitude-phasecombination to create a coordinate position for the location of the aircraft. The detection of amplitude and phase variation could help the system properly access the position of the aircraft. It allowed for the proper angular location of the object.

The mono-pulse radar system operates by comparing the cross-sectional area of objects to cancel the frequency characteristics of the delay line. The most utilized mono-pulse comparator uses a four-way in-phase power divider with an eight post wave guiding comparison system. The Ground Bridge system with the addition of Gysel power helps to shift the phase of the system. It, in turn, detects the position based on the phase of the system. The system uses a sequential lobe switching technique. The lobe switching technique allows the echo from the moving target to fluctuate along the Doppler spectrum (Bhilegaonkar & Dhande, 2013, p. 557; Raj, 2016, p. 7755). The echo system helped in determining the accurate position and phase of the system. The system accounted for the fluctuation created by the moving target.

The tracking system didn't account for the presence of permeability or conductivity among the layer of air through which radio waves travelled. It was later modelled for High-resolution tracking by Brothers et al. "The beam-forming nature allows the modification of the aircraft tracking system into a fixed wireless communication system" (Brothers, Cangeme, Flaig, 2002, p. 14). The entire mono-pulse system could be modified to form a wireless communication platform. These mere modifications allowed radar systems to have a wide range of applications in civilian fields. The drawbacks also suggested a need for a better tracking system which solved all the issue of mono-pulse tracking systems.

Moving-Target Indication (MIT) System

The moving-target indication (MIT) was a modified version of the mono-pulse tracking system. It could detect the target's velocity and estimate the position of the moving target. It used relative ground moving target indication (GMTI) to operate. A synthetic-aperture radar (SAR) is used to calculate the relative difference between the moving object and the stationary earth surface (Guo et al., 2011, pp. 3755–3756). The determination of relative difference allowed the system to note the velocity of the system. It estimated the relative velocity through an iterative adaptive approach. It also allowed the system to distinguish the moving and stationary objects from one another.

The robust parametric approach allowed the system to correctly distinguish between the misplaced and actual targeted body. Cross-linking and cross ranging could also be done through stationary clutter cancellation. It allowed the radar system to tabulate the velocity of clutter as zero. It was an added advantage that the mono-pulse tracking system didn't have in its arsenal. The SAR used an imagining mechanism to create an outer scene that mimics the natural environment. The position is indicated based on the Ground Moving Target Indication (GMTI) system. A single channel SAR could incoherently receive as much input as eight antennae mono-pulse tracking system.

The moving target system was adapted later on to eliminate blind speed and remove ambiguity in target presence. Various aircraft carriers adapted to the target indicator system and formulated ambiguity by sending frequency signals to disrupt the signal strength at various points. The GMTI based indication system needed to differentiate theambiguity given by aircraft. A modular multichannel amplitude-comparison carrier that used millimetre wave was added to the system. This allows the tracking device to collect and solve the problem of short interferometric transmission between various baselines.

"Certain distracting clutters that were obtained due to wind movement and speckle variation on various inclined angles were recognized"(Rüegg et al., 2007, p. 542).The two prevalent systems couldn't distinguish the peak signal level which helped separate an allied aircraft from a supporting vessel. Khan & Power (1995, p. 46) noted that a modulated frequency could help to blur the variation and change the radar response which caused the establishment of phased array systems. The phased array radar system, in turn, could blur the entire clutter frequency. It allowed the phased array radar system to replace the moving-target indication system from the radar scene. The phased array radar system then took over from the moving-target indication system as the most application radar system.

Phased Array Radar System

The use of radar system transferred from a mono-pulse tracking system to a multi-static radar system. Multi-static radar system used complex geometries to detect smaller stealthier aircraft (El-kamchouchy et al., 2013, p. 338). The phased array radar response system was more preferred than the two used systems as it could remove the defect which plagued both radar technologies.

The first phased array radar system was developed by Lincoln Laboratory in the late 1950s. The working of the radar system was in direct competition withthe Soviet's launch of Sputnik I in 1957. In the earlier years on the development of a phased array system, an array testing bed was kept on a cylindrical reflector surface. And, the whole system was then mounted to form an embryonic enclosed transmitter and receiver to receive and send signals.

The phased array radar system underwent long periodic changes in structure. The major components for the phased array system were log-periodic antenna structure with a low interconnected coupling device. A dipole radiator was attached to the low-noise front-end amplification system. An electron-beam parametric amplifier is used as it allowed for the configuration of the antenna system.

A major critical improvement was to move the radar beam electronically to detect signals passing through the critical zone. This created automation in the radar detecting system which gave the system an effective movement path. The radar system could continuously monitor without manual support (Fenn et al., 2000, pp. 332–333). This system is used in today's radar technology.

The multi-static phased radar system is nowadays modelled into a newer, complex radar system which combined all the isolated task of guiding missiles, tracking targets and searching for various volumes of space in systems. The newer designed phased array radar system is multifunctional and operates using various heuristic methods. The developed system could conduct the weapon guidance, tracking and surveillance job for the system. The phased array system also divides the overall searching area based on critical regions. It allows the system to create a priority list with a properly defined structure. "The automated multi-tasking robot allows control over the scheduling of various jobs and assigns them based on priority"(Orman et al., 1996, pp. 15–17). It allowed the radar system to separate the friendly threats from unfriendly threats automatically. The assigning of components automatically allowed the system to form a proper distribution and transmission hub.

A phased array radar system also helped to provide an optimal distribution of antenna providing proper transmitter signals. Centrally as well as remote located receiver and transmitter are also found in today's world (Stephens et al., 1989, p. 4). The distribution mechanism created by the phased array radar system allowed for proper large scale information transfer. The phased array radar system made it possible for the radar systems to have non-military application in the current scenario.

Radar systems nowadays have been modified to be ubiquitous in nature. The uses of microwaves in the radar system have been adopted because of their genuine benefits. Radar has been used to look over air-defence systems on both surface and airborne levels for decades and decades. A trend of civilian adaptation of radar systems has been possible because of the flexible adaptive nature of phased array systems(Forman, 1995, p. 398; Skolnik, 2002, p. 626). Most of the radar systems at the present are a mere modification of the phased array systems.

The phased array systems used in the current world are used for a variety of airborne and ground-based activities. Newer micro-electromechanical phase shifters, beam-forming photonic radars and adaptive space-time processing array radar are now in development. The developed radar could be cheap as well as allow a variety of operation modules and features. The era for phased-array radar is starting and will go on till the near future.

Conclusion

Phased-Array systems are the future of radar technology. The progressive research was slowed down in the 1950s and 1960s in comparison to the work done during the war. But the radar system progressed from a military weapon to a system that could be easily utilized at home. The modern forms of radar are all formed from the progressive growth of phased-array radar systems.

The weather-predicting radar also bears similarity to the mono-pulse tracking robot used for hunting planes back in the day. Even though the development of radar technology was done to have an edge in a possible futureimminent war, it has transitioned nicely into a force of data transmission and communication.

Air traffic control, environment sensing, navigation and speed measurement, all are done through the use of radar technology. The development of a phased array radar system acted as a beaming promise to the future. A great future exists in a combination of older radar technologies with the newer system to develop a sophisticated adaptive radar system.

The analogue-to-digital converter, digital beamforming and array modules all could be brought to a lower cost by combining pastphased array system with modern radar technology. Various civil applications such as planetary research and space surveillance have been possible only due to the establishment of the phased system. The system holds unwavering and unprecedented possibilities for the future and thorough research must be done to grasp the full potential of the radar system.The phased array radar system could formulate a possible cheaper alternative even in the 21st century.

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